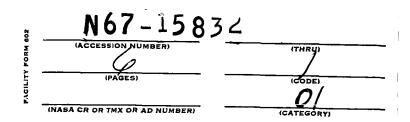NASA TT F-10,483

AERODYNAMIC CHARACTERISTICS OF RECTANGULAR PLATES IN HYPERSONIC FLOW OF A RAREFIED GAS

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AERODYNAMIC CHARACTERISTICS OF RECTANGULAR PLATES IN HYPERSONIC FLOW OF A RAREFIED GAS

M. D. Ladyzhenskiy and A. V. Lipin

The article discusses the experimental investigations of the aerodynamic characteristics of rectangular plates of equal area s, various aspect ratios λ and thickness d, at a Mach number of the unperturbed flow M=5.15, Reynolds number $R \approx 2 \cdot 10^2$, and angles of attack α varying from 0 to $40°$ for the purpose of determining the optimum shape of wings in a viscous hypersonic flow. The aspect ratio λ of the plates was varied in the range from 0.1 to 9 and their relative thickness $\delta = d/\sqrt{s}$ in the range from 0.025-0.16.

It was established that for fixed values of the area and of the thickness $\underline{/142}$* of a rectangular plate the variation in its maximum aerodynamic property $K_m(\lambda)$

in the investigated range of angles of attack has a maximum value when λ varies from 0.4 to 0.8.

1. Let us consider the flow around thin rectangular wings of fixed area with different aspect ratio, assuming that the surface temperature of the wing is much less than the stagnation temperature in the incident flow which is characteristic of hypersonic flights in the atmosphere. It is always possible to find such values of the wing's aspect ratio $\lambda \ll 1$ and $\lambda \gg 1$ for which a free molecular state of flow around the wing is realized. Assuming that the reflection of molecules from the surface of the body is completely of a diffusion nature, we find that in the considered limiting cases $\lambda \ll 1$ and $\lambda \gg 1$ at $M \to \infty$ the value of K_m is arbitrarily small.

If the characteristic area of the wing s is such that the Knudsen number $K = L/\sqrt{s} \ll 1$ (L is the mean free path of the molecules in the unperturbed flow), then when the aspect ratio is of the order of unity, the flow around the wing will be governed by the laws of a continuous medium. In this case, as we know, $K_m \neq 0$. Thus in a viscous hypersonic flow we can expect a maximum value of K_m

when the aspect ratio of the wing lies from $\lambda \ll 1$ to $\lambda \gg 1$, whereas in the region of large Reynolds numbers, K_m increases with λ. The boundaries for which the

flow is close to a free molecular flow approach each other as K increases.

2. In order to verify this fact experimentally and to determine the op- $\underline{/143}$ timum values of λ, the aerodynamic characteristics of models were investigated

in a vacuum wind tunnel at Mach numbers M=5.15 and Reynolds numbers $R_l = 2.3 \cdot 10^2$,

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*Numbers given in margin indicate pagination in original foreign text.

computed from the parameters of the perturbed flow and from the characteristic length $\iota=\sqrt{s}$. The models consisted of rectangular plates of equal area s, different aspect ratio $\lambda=0.1-9$ and relative thickness $\delta=0.025-0.16$. The air temperature in the injector chamber was equal to $T_0 =293°K$.

In the course of the experiment the normal and tangential components of aerodynamic forces acting on the model were measured while the angle of attack α was varied from 0 to 40°.

Figures 1 and 2 show a comparison of experimental relationships $C_x(\alpha)$ and $C_y(\alpha)$ (solid curves) with the results of calculations carried out by means of the theory of free molecular flow for the case of total diffusion reflection (ref. 1) (broken curves), for 2 models with different λ and the same relative thickness $\delta=0.029$. It should be pointed out that the theoretical values of the lift coefficients C_y are in better agreement with experimental values than the values of the drag coefficients C_x.

Figure 3 presents the variation in the coefficient of the normal force C_N as a function of the quantity $\zeta=M\alpha/\sqrt{s}\chi$, $\chi=M^3/\sqrt{R_b}$, $\epsilon=\varkappa-1/\varkappa+1$ for a series of models of the same thickness $\delta=0.029$, different values of λ ($9.18 \leq \lambda \leq 0.112$) and with $\alpha=10$ and 20°. Here R_b is the Reynolds number determined from the parameters of the unperturbed flow and from the characteristic length equal to the wing chord
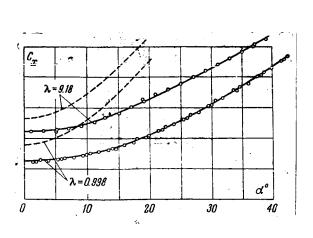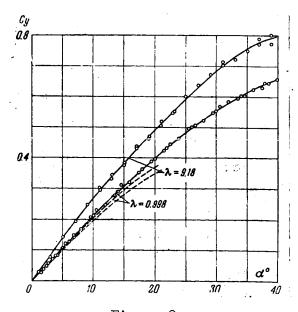

Figure 1.

Figure 2.

b, $\varkappa$ is the ratio of specific heats. The same figure shows the theoretical curve computed by V. S. Galkin using the method described in reference 2 for an infinitely thin plate. Investigations showed that for small aspect ratios ($\lambda < 0.15$) rectangular wings can be computed by using the theory of transverse poles since the values of C_N for $\lambda = 0.156$ and $\lambda = 0.112$ practically coincide.

It was established experimentally that as λ decrease the drag coefficient C_{x0} decreases when $\alpha = 0$. This situation is explained both by the increase in the bluntness as well as by the increase in the effective Reynolds number R_b.
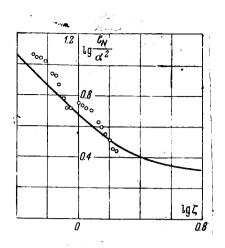

Figure 3.

When $\lambda < 1$ the theory of plane cross sections is no longer valid. In this case the quantity C_{x0} decreases at a lower rate /144 and for wings of small aspect ratios ($\lambda < 0.25$) it remains practically constant.

As λ decreases there is a decrease in $(dC_y/d\alpha)_{\alpha=0}$, which, apparently, can be explained by the increased effect of transverse gradients when going over to wings of small aspect ratios and by the decreased effect of the interaction of the boundary layer with the nonviscose flow.

The results are summarized in figure 4 which shows the functions $K_m(\lambda)$ and $\alpha_m(\lambda)$ (α_m is the angle of attack at which the value K_m is reached) for two values of relative plate thickness $\delta = 0.029$ and 0.084. It follows from this graph that in a viscous hypersonic flow the value of K_m for a rectangular plate of fixed are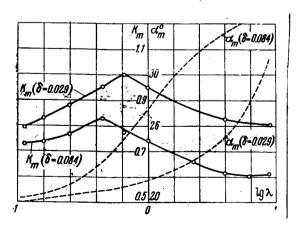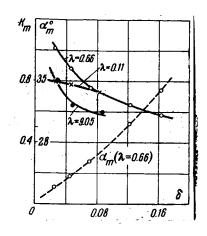a and thickness, i.e., of fixed volume, has a maximum when λ is varied. In the considered range of δ ($0.025 \leq \delta \leq 0.16$) this maximum is achieved in the range when λ varies from 0.4 to 0.8, and $K_m \approx 1$ when $\delta = 0.029$ while $K_m \approx 0.85$ when $\delta = 0.084$.

It is natural that as δ decrease the values of K_m for plates of small aspect ratios ($\lambda \sim 0.1$) increase insignificantly while for plates of large aspect ratios ($\lambda \sim 10$) the values of K_m increase to a larger extent.

From the standpoint of the theory it is interesting to consider whether

Figure 4.

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Figure 5.

there is a maximum in the function $K_m(\lambda)$ in the

case when the plate is infinitely thin. An answer to this question is given by the analysis of the variation in K_m as a function of δ (fig. 5) for

models with aspect ratios $\lambda = 0.1$, 0.44 and 9. Extrapolating these functions to the value $\delta = 0$, we can maintain that the maximum value of $K_m(\lambda)$ also

exists for an infinitely thin plate. The data presented in figure 5 makes it possible to determine α_m, corresponding to the value $\delta = 0$.

It should be pointed out (fig. 4), that the angle of attack α_m, for which the maximum value of

K_m is achieved, decreases as λ decreases for wings with a fixed value of δ.

As a result of this there will be a decrease in the heating of the plate.

Thus, from the standpoint of lift properties, wings with small aspect ratios ($\lambda < 1$) in a viscous hypersonic flow are advantageous compared with wings of large aspect ratios ($\lambda > 1$), which is contrary to what happens at high Reynolds numbers.

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